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THE DESIGN AND FABRICATION OF A PROTOTYPE INFLATABLE
HEATED CASUALTY EVACUATION UNIT

Robert W. Ellis, et al

ARTECH Corporation

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September 1975

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THE DESIGN AND FABRICATION OF A PROTOTYPE INFLATABLE HEATED CASUALTY EVACUATION UNIT

Final Report

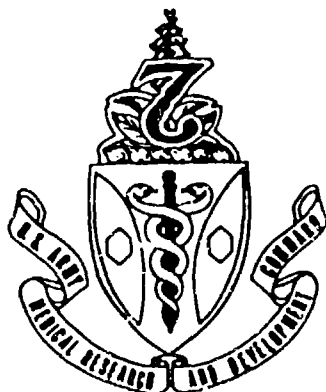
Robert W. Ellis
R. William Smith
Frank E. Swindells

September 1975

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND

Washington, D.C. 20315



Contract No. DAMD17-74-C-4129

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of a portable, inflatable, electrically heated and thermostatically controlled casualty evacuation unit. The ARTECH prototype utilizes good insulation properties coupled with thermal energy storage materials to maintain a casualty for 2 hours at a comfortable temperature (50°F or better) if a loss of power occurs. The unit can be heated with three separate power sources including 24 Vdc, 28 Vdc and 115 Vac. When the unit is deflated, it can be folded to less than 2 cubic feet for storage and weighs approximately 35 lbs.

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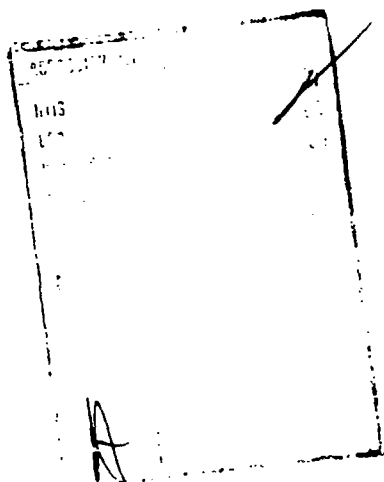
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SUMMARY

The requirement exists for a field-portable casualty evacuation unit for the handling of sick and injured personnel in an arctic environment. Such a unit must provide a means for placing a casualty into a controlled environment within a short time after the injury or sickness occurs, and maintaining it until such time as the casualty can be evacuated and received at a treatment facility. ARTECH CORP. has designed and fabricated a prototype of a portable, inflatable, electrically heated and thermostatically controlled casualty evacuation unit. The ARTECH prototype utilizes good insulation properties coupled with thermal energy storage materials to maintain a casualty for 2 hours at a comfortable temperature (50°F or better) if a loss of power occurs. The unit can be heated with three separate power sources including 24 Vdc, 28 Vdc and 115 Vac. When the unit is deflated, it can be folded to less than 2 cubic feet for storage and weighs approximately 35 lbs.



FOREWORD

This report represents the work done under Contract DAMD17-74-C-4129 during the period 74 Jul 1-75 Jul 31. The Contracting Officer's Technical Representative was Mr. Joseph T. Doyle. The Principal Investigator for ARTECH CORP. was Dr. Frank E. Swindells. The Project Engineer was Robert W. Smith. The design and selection of materials used for the inflatable evacuation bag was performed by Mr. Smith aided by Phil Trumphour. The thermal energy storage salts were formulated and tested by Warren Kerlin and packaged by Mr. Smith and Mr. Trumphour under the direction of Dr. Swindells. The selection of the flexible heaters and design of the proportional AC/DC temperature controller was performed by Robert W. Ellis. Mr. Ellis and Mr. Smith interfaced the heaters, wiring, temperature sensor and the controller with the remainder of the design.

The laboratory support by the sponsoring agency's technical lab at Ft. Detrick, Maryland is gratefully acknowledged.

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1.0 INTRODUCTION

It was ARTECH's objective under Contract DAMD17-74-C-4129 to study the requirements for and design and fabricate a prototype of an inflatable, electrically heated casualty evacuation unit. The following requirement for a heated patient bag as obtained from the U.S. Army Medical Research and Development Command served as the guideline for the design and fabrication of ARTECH's prototype:

a. Requirement. There is a requirement for development of an insulated, heated, bag for the handling of sick and injured personnel in an arctic environment.

b. Purpose. To provide a means of handling sick and injured personnel in a controlled environment as soon after the injury or sickness occurs, until the individual can be evacuated and received at a treatment facility. Without this item, hypothermia and secondary cold injuries result. Present methods of tents and heaters in large quantities at aid stations are inadequate and impractical.

c. Operational Characteristics. This will be a system composed of a heated, insulated bag, and a washable or disposable liner. The system will be designed to perform in the environment described in AR 70-38, Category 7, (Cold), para 2-13, but may have application in other areas of the world during certain periods of low temperatures when the danger of cold injury is present.

Additional operational detail is divided into two sections, one defining the holding and evacuation bag parameters and the other, the liner parameters.

(1) A heated patient holding and evacuation bag.

a. (Essential) Capable of providing regulated heat to a bag large enough to contain an individual with field expedient splints applied to one or more of his extremities, and utilizing multiple electrical power sources selected by the operator from those normally found in a forward combat area (i.e., 110 volt AC, 24 volt DC, 28 volt DC). (Essential) Design and construction shall preclude possibility of electrical shock to the patient.

b. (Essential) Capable of retaining a temperature within the occupied bag of not less than "+50°F" for two hours after removal of power with ambient air temperatures down to "-50°F" and wind velocities of up to 10 knots.

c. (Essential) Constructed of waterproof materials which will protect against wind and which will not cause dermatitis or complications to wounds or burns.

d. (Essential) Constructed of materials with a lusterless reversible surface, one side which is capable of being produced in camouflage white, and the other side in camouflaged white-tan-forest green pattern.

e. (Essential) Constructed of materials which will not continue to burn when a flame is removed, and after the application of flame, the material will not be considered severely damaged when tested by Federal Specification CCC-T-191, Textile Test Methods, (Method 59.03).

f. (Essential) Constructed of materials which will protect the individual in the bag against a thermal flash of 10 cal/sqcm/sec. (Desirable) 30 cal/sqcm/sec.

g. (Essential) Constructed so as to provide protection to the patient's face, from the wind, and at the same time permit normal breathing.

h. (Essential) Constructed so as to permit the patient in the bag to operate the opening and closing devices sufficiently to allow escape from the bag under emergency conditions.

i. (Essential) Constructed with a heating system capable of maintaining a patient in a controllable temperature environment of "70°F," $\pm 5^\circ\text{F}$. However, a temperature depression of 10°F is acceptable for periods no longer than one hour. In addition, the temperature differential between any two points within the bag shall be no greater than 10°F at any one time. This capability must be available for periods up to eight hours, when the bag with the patient inside is placed on snow covered ground and the ambient air temperature is -50°F with wind velocities up to 10 knots.

j. (Essential) The system must be capable of preventing temperatures above "90°F" at the patient's skin.

k. (Essential) The system must operate safely without attention with a patient in the bag for a period of eight hours.

l. (Essential) The capability must exist to readily change the power source at any time.

m. (Essential) Constructed with handles or loops to provide the ability to lift the bag with patient inside.

n. (Essential) Capable of warming the bag's interior environment, without patient, from "-50°F" to "+50°F" in five minutes.

o. (Essential) The bag must be able to perform and be maintained under conditions described in AR 70-38, para 2-13.

p. (Essential) The bag will be capable of being operated by a man with the MOS of 91B20, with no additional training except at unit level on an informal basis.

q. (Essential) The weight of the bag shall not exceed 25 pounds (Desirable) 15 pounds.

r. (Essential) The overall cube of expanded bag will not exceed 25 cubic feet, and when bag is rolled for storage the cube will be 3 cubic feet or less.

s. (Desirable) Constructed of materials which can be easily decontaminated with standard decontaminants.

(2) A liner, compatible with the basic bag will have the three (3) following additional properties:

a. (Essential) Capable of being laundered and sanitized by standard field laundry equipment, or be disposable if replacement costs are reasonable (less than cost of a non-disposable liner to include launder life and costs).

b. (Essential) Constructed of materials that will prevent human secretions from soiling the bag, but at the same time will not cause dermatitis or complications to wounds and burns and is comfortable to the patient.

c. (Essential) Capable of being changed by one person, unassisted, in five minutes. (Desirable) Using assembly-line techniques, two minutes.

ARTECH followed the operational requirements as closely as practical for the design of an initial prototype with the understanding that refinements could be more easily worked out after a design review of the unit. Requirements such as overall weight and rapid warm up were relaxed to allow concentrated development of a well-insulated bag with thermal storage capability.

2.0 PRIMARY DESIGN CONSIDERATIONS

In light of the requirements as stated in the introduction, primary design considerations included human factors as well as thermodynamic concerns. Among the human factors considered were anatomy, body comfort and the generation of body heat by an injured or wounded individual.

It is essential that the Patient Bag be designed to accommodate comfortably the fully clothed human body in either the prone or the supine position. The minimum interior dimensions of the Bag should describe a space envelope sufficiently large to contain the body of the 95th percentile male in the military population while clothed in heavy or bulky arctic clothing or flight suit. Figures 1 and 2 are plan and elevation views showing the minimum dimensions of a body space envelope satisfying these requirements. The dimensions shown in these figures are based upon generally accepted available anthropometric data⁽¹⁾ as shown in table 1.

An examination of figure 1 reveals that the maximum width of the minimum body space envelope is 22.5 inches. This dimension is based upon the shoulder breadth of the 95th percentile male clad in heavy clothing.

These data were used as primary guidelines in the physical dimensions of the prototype as designed.

The average basal metabolic rate (BMR) for resting men in their early twenties may be adequately described for 90% of this population by a figure of 40 kcal/square meter of body surface/hour, with a range of $\pm 15\%$. This average value declines with increasing age. The relationship of surface area to mass varies with body type; an individual who is stocky but not obese may have a ratio as high as $285 \text{ cm}^2/\text{kg}$ while a lanky person may range as low as $235 \text{ cm}^2/\text{kg}$. An average figure has been determined as $268 \text{ cm}^2/\text{kg}$.

Evaporative heat loss, largely through expired air saturated with water vapor, will account for about 20-30% of the basal heat dissipation. The figures given in table II are for an average individual of 185 lb and two others who represent the extremes of heat production.

(1) Human Engineering Guide to Equipment Design
(Morgan, Cook, Chapmans and Lund, Editors)
New York; McGraw-Hill, 1963, Chap. 11, p. 485 ff.

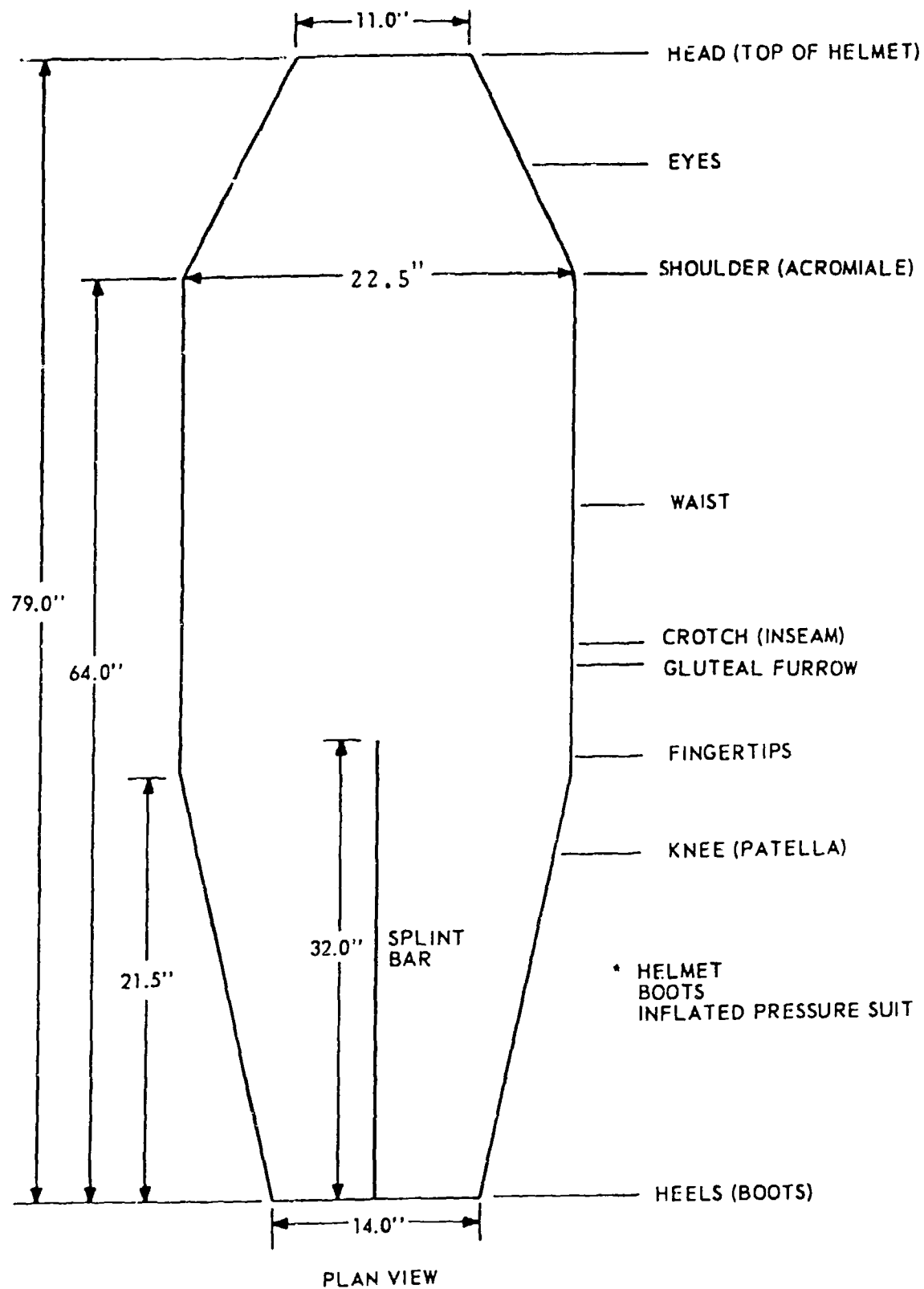
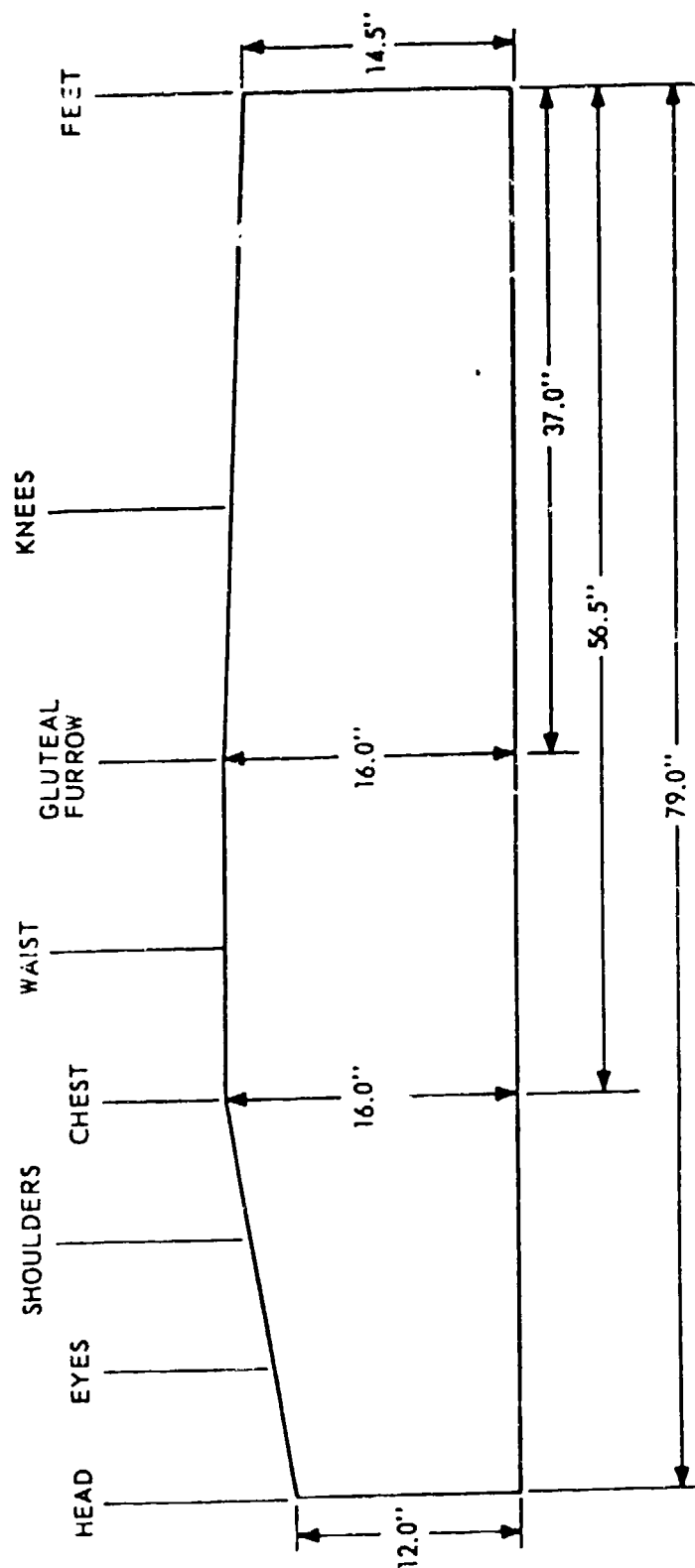


Figure 1. Minimum body space envelope (plan view).



• HELMET
BOOTS
INFLATED PRESSURE SUIT

Figure 2. Minimum body space envelope (elevation view).

TABLE 1
Description of 95th Percentile Man

<u>Nude Heights (Inches)</u>		<u>Clothing Increments</u>			<u>Design Basis</u>
		<u>Flying Boots</u>	<u>Flying Helmet</u>	<u>Safety Factor</u>	
Stature	73.1	1.3	2.6	.2	77.2
Eyes	68.6	1.3		.2	70.1
Shoulders	60.2	1.3		.2	61.7
Waist	45.0	1.3		.2	46.5
Crotch (inseam)	35.7	1.3		.2	37.2
Knuckles	32.4	1.3		.2	33.9
Knee (Patella)	21.9	1.3		.2	23.4

<u>Nude Breadths (Inches)</u>		<u>Clothing Increments</u>			<u>Design Basis</u>
		<u>Flying Helmet</u>	<u>Heavy Clothing</u>	<u>Safety Factor</u>	
Head	6.4	4.3		.2	10.9
Shoulders	19.4		.7	.2	20.3
Chest	13.4		.6	.2	14.2
Waist	12.3		.6	.2	13.1
Hip to Hip	14.4		1.3	.2	15.9
Knee to Knee	8.8		2.5	.2	11.5
Both Feet	8.2		2.4	.2	10.8
One Heel	2.9		1.2		4.1

Nude Weight: Approximately 201 pounds; add 25 pounds for heavy winter clothing.

T A B L E II

Heat Generated by Various Body Types and Weights

Body Type and Weight	Area Weight		Total Area m^2	$\frac{\text{kcal}}{\text{m}^2 \text{ hr}}$	Heat Evolution		BMR Loss by Evaporation	Net Heat Evolution BTU/hr
	$\frac{\text{cm}^2}{\text{kg}}$	$\frac{\text{lb}}{\text{m}^2}$			$\frac{\text{kcal}}{\text{hr}}$	$\frac{\text{BTU}}{\text{hr}}$		
140 lb	235	93.9	1.49	34	50.7	201.3	30%	140.9
185 lb	268	82.2	2.25	40	90.0	357.3	25%	268.0
230 lb	285	77.4	2.97	46	136.6	542.3	20%	433.8

The insight gained by the human factors discussed above guided the design toward the final prototype design as delivered. The shape of the evacuation bag was basically governed by the minimum space envelope of a fully clothed, arctic-equipped 95th percentile man as depicted in figures 1 and 2. The construction techniques and materials were dictated by the given requirements as well as the desire to add the inflatable feature for compact storage and increased patient comfort.

Since the design was to incorporate this inflatable feature, the natural design approach was to utilize the insulating properties of the dead air space resulting from inflation. The insulation was enhanced by attaching a layer of aluminum metallized nylon reinforced polyethylene material ("space blanket") to the inner surface of the structure.

With these factors in mind, a suitable method of determining the thermodynamic properties was selected. In Kent's Mechanical Engineering Handbook(2), the overall heat transmission coefficient is defined as follows:

$$U = \frac{1}{\sum_{i=1}^n \frac{1}{R_1 + R_2 + R_3 + \dots + R_n}}$$

where:

U = the overall heat transmission coefficient

R = the thermal resistance of each surface or structural layer

$$= \frac{1}{f} \text{ or } \frac{1}{c}$$

where:

f = effective surface conductance

c = conductance for heat flow through a layer of specified structure.

(2) Salisbury, J. K., Kent's Mechanical Engineers' Handbook, Power, New York, John Wiley & Sons, Inc., 1967, Section 12-08, Table 5.

For the prototype heated patient bag,

$$U = \frac{1}{R_1 + R_2 + R_3 + R_4}$$

where

$$R_1 = 1/f_i,$$

$$R_2 = \text{resistance of the space blanket} = 1.7 \text{ clo} \\ = 1.496 \text{ ft}^2 \text{ hr } ^\circ \text{F/BTU}$$

$$1 \text{ clo} = 0.88 \text{ ft}^2 \text{ hr } ^\circ \text{F/BTU}$$

$$R_3 = 1/c,$$

$$R_4 = 1/f_o$$

where

$$f_i = \text{surface conductance of still air} \\ = 1.65 \text{ BTU/ft}^2 \text{ hr } ^\circ \text{F}$$

$$c = \text{conductance of air space bounded by foil} \\ = 0.46 \text{ BTU/ft}^2 \text{ hr } ^\circ \text{F}$$

$$f_o = \text{surface conductance of air with a velocity of} \\ 15 \text{ mph} = 5.0 \text{ BTU/ft}^2 \text{ hr } ^\circ \text{F}$$

$$U = 0.225 \text{ BTU/ft}^2 \cdot \text{hr} \cdot ^\circ \text{F}$$

The maximum conditions for heat loss occur when the outside temperature $T_o = -50^\circ \text{F}$ and the inside temperature $T_i = 70^\circ \text{F}$. Therefore, the maximum heat loss is calculated from:

$$Q_o = UA_s \Delta T$$

where

$$Q_o = \text{heat loss rate}$$

$$A_s = \text{surface area}$$

$$\Delta T = \text{temperature differential}$$

This value of U then will be used in the formula above to calculate the heat loss rate for the casualty evacuation bag to determine the amount of thermal energy storage (TES) materials necessary as well as the electrical power requirements. These requirements are reduced nominally because of the minimal 100 BTU/hr generated by the metabolic processes of the slightest human, even in shock.

3.0 PROTOTYPE DESIGN

3.1 Inflatable Bag

The casualty evacuation bag was designed to be inflatable, adaptable to manufacturing techniques and self-supporting in addition to meeting the stated requirements. The result of the design effort by ARTECH was two separately inflatable air mattresses, a top and a bottom. The top section, which is basically a canopy with a hooded head attachment, is hinged to the bottom section and attached by a zipper on the three remaining, unhinged sides (See Figure 3). The arctic type hood has a synthetic fur piece to protect a patient's face from windburn but still allow normal breathing. The bottom section is a rectangular air mattress which forms a reasonably air tight seal with the top canopy section when fastened in place with the zipper.

The materials allow dielectric heat sealing as well as adhesive bonding techniques. Standard commercially available valves, similar to those currently used in life rafts, were used for inflation and pressure relief.

The inflatable sections were lined with a layer of aluminum metallized nylon reinforced polyethylene material ("space blanket") which adds additional insulation to the design.

Surface area calculations, necessary for determining heat loss, power requirements, heater requirements and TES materials requirements were made from the data in figure 4. The figure represents the inner volume of the prototype when inflated and fastened. The design dimensions are intended to allow a fully dressed, arctic-equipped, 95th percentile wounded man to be comfortably enclosed within the zipped prototype.

The calculations are based on the assumption that under severe arctic conditions, with a 15 mph wind blowing, the evacuation unit will be resting on the ground. Therefore the heat loss from the top section will be appreciably greater than the heat loss from the bottom section. To compensate for this, a greater concentration of heaters was designed into the top section than the bottom section.

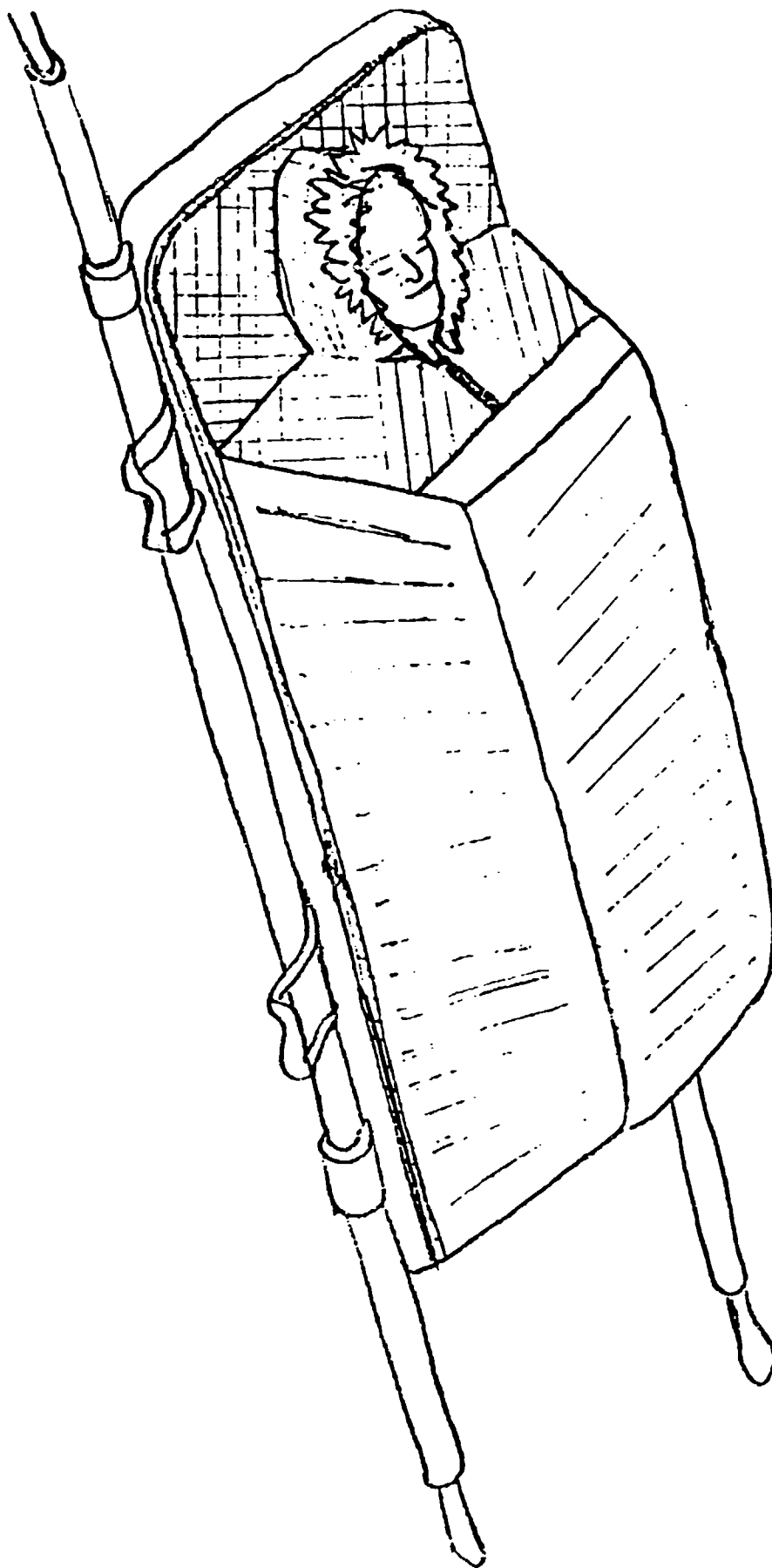


Figure 3. Sketch of the prototype evacuation bag on a litter.

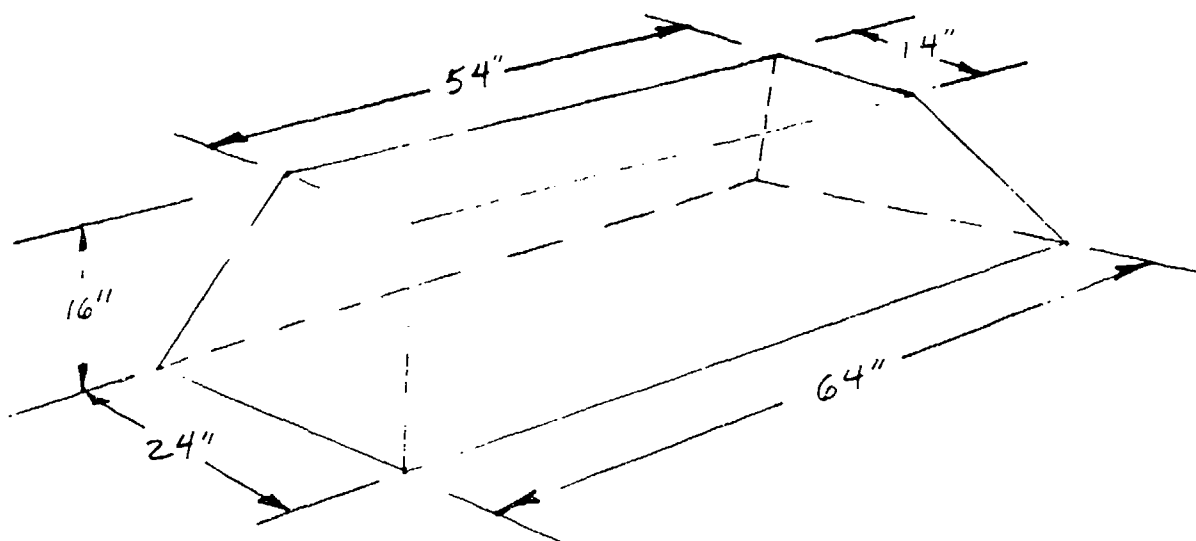


Figure 4. Sketch of the inner volume of the prototype when inflated and fastened.

The calculations are as follows:

$$A_s = 34.1 \text{ ft}^2 = \text{Total Surface Area}$$

$$A_{st} = 23.42 \text{ ft}^2 = \text{Top Surface Area}$$

$$A_{sb} = 10.67 \text{ ft}^2 = \text{Bottom Surface Area}$$

Referring back to previous calculations, the heat transmission coefficient for the top section is

$$U_t = 0.2251 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F}$$

The heat transmission coefficient for the bottom section, will have to be calculated as follows.

$$U_b = \frac{1}{R_{1b} + R_{2b} + R_{3b} + R_{4b}}$$

where

$$R_{1b} = 1/f_i$$

$$R_{2b} = 1.496 \text{ ft}^2 \text{ hr } ^\circ\text{F/BTU}$$

$$R_{3b} = 1/c$$

$$R_{4b} = 1/f_o$$

where

$$\begin{aligned} f_i &= \text{inner surface conductance of still air} \\ &= 1.65 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F} \end{aligned}$$

$$\begin{aligned} c &= \text{conductance of air space bound by foil} \\ &= 0.46 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F} \end{aligned}$$

$$\begin{aligned} f_o &= \text{outer surface conductance with still air} \\ &= 1.65 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F} \end{aligned}$$

$$U_b = 0.2048 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F}$$

Now the heat loss rates for the top and bottom sections are found as follows:

$$\begin{aligned}Q_{ot} &= U_t A_{st} \Delta T \\&= 0.2251 \times 23.42 \times 120 \\&= 632.62 \text{ BTU/hr}\end{aligned}$$

$$\begin{aligned}Q_{ob} &= U_b A_{sb} \Delta T \\&= 0.2048 \times 10.67 \times 120 \\&= 262.23 \text{ BTU/hr}\end{aligned}$$

$$\begin{aligned}Q_{oTot} &= Q_{ot} + Q_{ob} \\&= 894.85 \text{ BTU/hr}\end{aligned}$$

The heat generated by a casualty is at least 100 BTU/hr which gives a total heat loss rate

$$\begin{aligned}Q_{Total} &= 794.85 \text{ BTU/hr} \\&= 232.41 \text{ Watts}\end{aligned}$$

The total heat loss rate of 232.41 watts is an indication of how much power or heat is necessary to put into the casualty bag to maintain the temperature at 70°F under worst conditions of temperature. A reasonably safe power to apply to the prototype was selected as 250 watts.

3.2 Carrying Harness

From drawings available a standard carrying harness such as in current use in field evacuation situations was found adaptable as a means of lifting the prototype evacuation unit. There are three hand grips on each side and one in the front to allow possible dragging of the unit by a single individual (see figure 5). The prototype harness was fabricated from 1 3/4 in. nylon webbing material which was on hand, but a 2 in. cotton webbing is preferable due to ease of fabrication, and better low temperature handling properties.

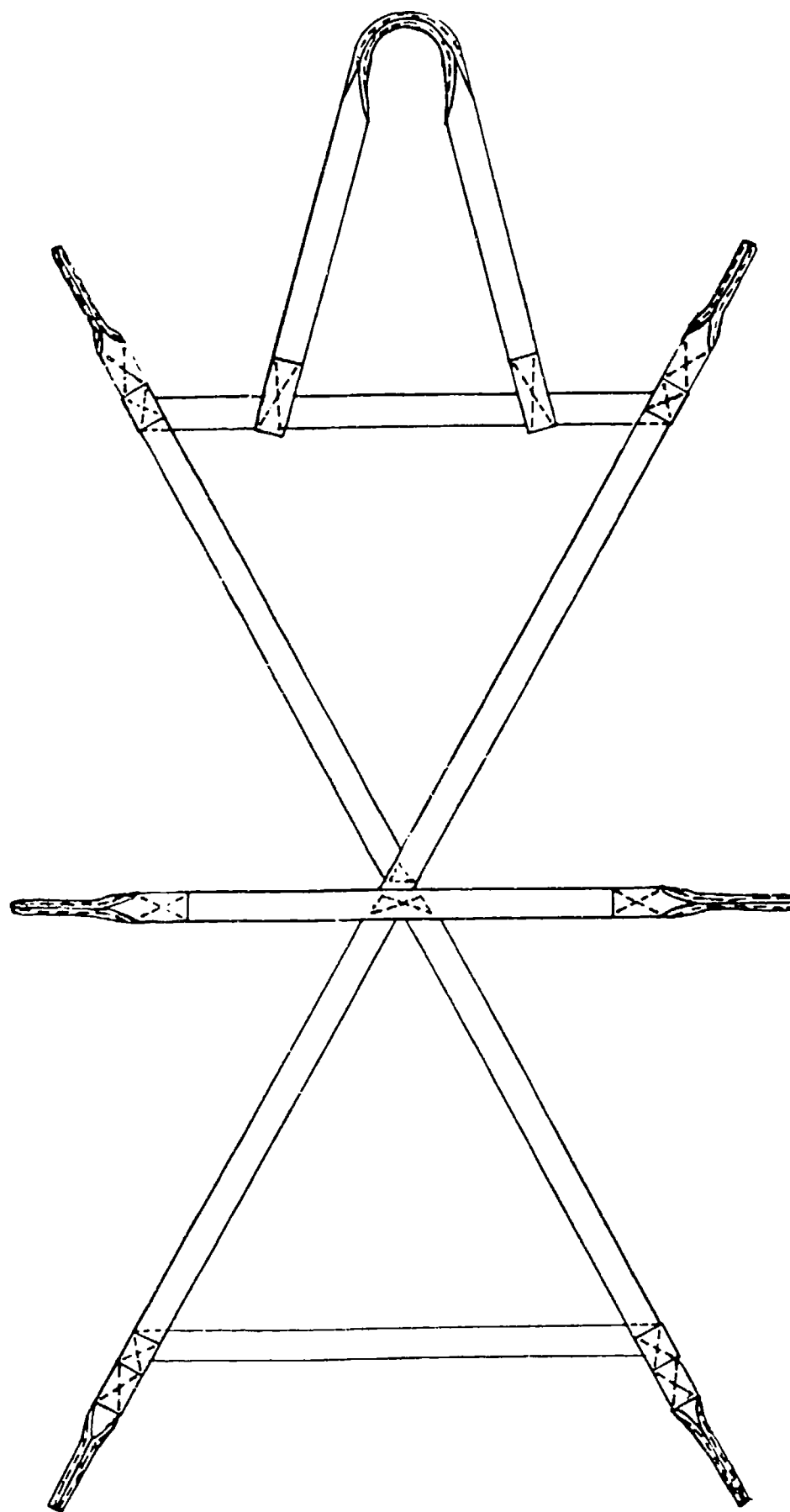


Figure 5. Sketch of the carrying harness.

3.3 TES Material

The TES material is a nucleated gel of $\text{Na}_2\text{SO}_4\text{-NH}_4\text{Cl-H}_2\text{O}$ eutectic designed to have the following properties:

Melting and Freezing Point	65°F
Heat of Fusion, Q_f	80 BTU/lb
Density	94 lb/ft ³
C_p , Specific Heat when liquid	0.78 BTU/°F·lb
C_p , Specific Heat when solid	0.42 BTU/°F·lb

However, when tested under rapid cooling conditions (down to -30°F), the freezing temperature was closer to 55°F due to a supercooling effect. The TES system was added to compensate for the rapid heat loss from the casualty bag under worst conditions. The TES materials add inertia to the system which the air alone lacks and aid in temperature control. These materials yield the considerable energy evolved in a phase change from liquid to solid as well as the sensible heat evolved during cooling. As cooling proceeds, the temperature drops to the freezing point of the TES material where it remains until all of the material is frozen. Due to the high latent heat of the phase change, a comparatively large amount of heat is evolved which serves to maintain the temperature of the enclosure, temporarily replacing the electric heating.

The calculations for determining how much TES material was necessary are as follows:

Heat loss from enclosure = q

$$q = [UA_s(T_i - T_o) - 100] \text{ BTU/hr}$$

$$T_o = -50^\circ\text{F}$$

$$P_1 = \text{hours in liquid state, } T > 55^\circ\text{F}$$

$$P_2 = \text{hours during phase change, } T = 55^\circ\text{F}$$

For the Top section, ignore the 100 BTU/hr from injured occupant:

$$\begin{aligned}
 q &= [U_t A_{st} (T_i - T_o)] \text{ BTU/hr} \\
 &= [0.2251 \times 23.42 (T_i - T_o)] \text{ BTU/hr} \\
 &= [5.272 (T_i - T_o)] \text{ BTU/hr} \\
 q_{1t} &= [5.272 (T_i + 50)] \text{ BTU/hr} \\
 q_{2t} &= [5.272 (105)] \text{ BTU/hr} \\
 &= 553.54 \text{ Btu/hr}
 \end{aligned}$$

Also $q = MC_p \frac{dT_i}{dt}$

where

M = mass in lb

C_p = Temperature coefficient for TES materials
in liquid state
 $= 0.78 \text{ BTU/}^\circ\text{F lb}$

During P_{1t}

$$\begin{aligned}
 - \frac{dT_i}{dt} &= \frac{q_{1t}}{M_t C_p} = \frac{5.272 (T_i + 50)}{0.78 M_t} \\
 &= \frac{5.272 T_i + 263.6}{0.78 M_t} = \frac{6.759 T_i + 337.94}{M_t} \\
 P_{1t} &= \int_0^{P_{1t}} dt = - \int_{70}^{55} \frac{M_t dT_i}{6.759 T_i + 337.94}
 \end{aligned}$$

Since $\int \frac{dx}{a + bx} = \frac{1}{b} \log (a + bx)$

$$\begin{aligned}
 P_{1t} &= \frac{M_t}{6.759} \left| \log (337.94 + 6.759 T_i) \right|_{55}^{70} \\
 &= \frac{M_t}{6.759} (\log 811.02 - \log 709.68) \\
 &= \frac{M_t}{6.759} (0.05799) \\
 &= 0.00857 M_t
 \end{aligned}$$

$$P_{2t} = \frac{M_t Q_f}{q_{2t}}$$

where

$$Q_f = \text{heat of fusion for TES materials}$$

$$= 80 \text{ BTU/lb}$$

$$P_{2t} = \frac{M_t \cdot 80}{553.54}$$

$$= 0.14452 M_t$$

$$P_{1t} + P_{2t} = 2 \text{ hr}$$

$$2 = 0.00857 M_t + 0.14452 M_t$$

$$= 0.15309 M_t$$

$$M_t = 13.06 \text{ lb}$$

For the Bottom section;

$$q = U_b A_{sb} (T_i - T_o) - 100$$

$$= (0.2048)(10.67)(T_i - T_o) - 100$$

$$= 2.185 (T_i - T_o) - 100$$

$$q_{1b} = 2.185 (T_i - 50) - 100$$

$$q_{2b} = 2.185 (105) - 100$$

$$= 129.45 \text{ BTU/hr}$$

During P_{1b}

$$- \frac{dT_i}{dt} = \frac{q_{1b}}{M_b C_p}$$

$$= \frac{2.185 T_i + 9.261}{0.78 M_b}$$

$$= \frac{2.8 T_i + 11.873}{M_b}$$

$$\begin{aligned}
P_{1b} &= \int_{55}^{70} \frac{M_b}{2.8 T_i + 11.873} dT_i \\
&= \frac{M_b}{2.8} \left| \log (11.873 + 2.8 T_i) \right|_{55}^{70} \\
&= \frac{M_b}{2.8} (\log 207.873 - \log 165.87) \\
&= \frac{M_b}{2.8} (2.3178 - 2.2197) \\
&= \frac{M_b}{2.8} (0.09802) \\
&= 0.035 M_b
\end{aligned}$$

$$\begin{aligned}
P_{2b} &= \frac{M_b Q_f}{q_{2b}} \\
&= \frac{M_b 80}{129.45} \\
&= 0.61799 M_b
\end{aligned}$$

$$\begin{aligned}
Z &= P_{1b} + P_{2b} \\
&= 0.035 M_b + 0.61799 M_b \\
&= 0.653 M_b
\end{aligned}$$

$$M_b = 3.063 \text{ lb}$$

$$\begin{aligned}
M_{\text{Total}} &= M_t + M_b \\
&= 12.915 + 3.063 \\
&= 15.97 \text{ lb}
\end{aligned}$$

This of course implies that 16 lb of fully charged TES material will compensate for the heat loss from the enclosure and maintain a casualty at 50°F or better for 2 hr after loss

of power. Under less extreme conditions, the patient can be maintained at the prescribed temperature longer than 2 hr.

3.4 Heaters

The 250 watts of power applied to the load is in the form of heat, distributed in the top and bottom sections of the prototype proportional to the heat loss rates. That is, 30% of the heaters were placed in the bottom section and 70% in the top section, since the heat loss rate for the bottom section is 30% of the total heat loss rate and that for the top is 70% of the total.

Thirty heaters were connected in parallel with the output from the temperature controller to provide the heat necessary and limit the surface temperature of the heaters to 90°F. This prevents a patient's skin from coming into contact with an uncomfortably hot temperature. Each heater will draw approximately 1/3 ampere when power is present at the load (28 Vdc). Of course the current will be less for 24 Vdc input. The current through each heater can be adjusted within this desirable range as necessary with an AC power input (115 V, 60 Hz only) because of a built-in adjustment on the AC power module. The heaters are connected to the temperature controller output with a two-pin male connector.

3.5 Liner

A prototype liner was designed to cover the bottom section of the evacuation bag. It fastens on very quickly (30 seconds) by one snap located in each of the 4 corners. The liner is launderable, durable and flame retardant. It covers the heaters and space blanket on the bottom section and adds an additional bit of insulation.

3.6 Power and Temperature Controller

The power necessary to heat the prototype casualty evacuation bag has been calculated to be 250 watts nominally. The controller will be operable from 28 V dc, 24 V dc and 115 V ac and provide a proportional output to the load. This means the power will be controlled in such a way as to reduce the power to the load as the temperature within the enclosure nears the set point and to increase the power to the load as the temperature drops. This method tends to prevent temperature overshoot which occurs with other methods of temperature control such as on-off control.

The controller consists of 4 modules which can be replaced individually when defective. These are; the basic DC-operated proportional temperature control module, the DC output device, the AC output device and a 12 V dc miniature power supply. The controller has an off-on switch which also switches between AC and DC inputs and two terminals for power input connections (figure 6). The AC module is a specially developed hybrid device which serves the dual function of phase controlling the AC input to the level necessary for safe and proper heating and switching that AC output via an optically isolated set of DC control terminals. The temperature control module provides a control signal to the DC output module, (a 16 ampere Darlington transistor mounted on a heat sink) which causes the device to switch on and off at a rate proportional to the temperature at the sensor of the temperature control module. When the switch is set on DC, the DC module conducts full load current. On the AC setting, the AC module conducts full load current but the AC module is controlled by the DC module's output. Both output modules conduct approximately 10 amperes and each has a heat sink. The switching of inputs is accomplished with a single 4PDT switch which switches the input terminals to the proper position and the load to the proper output module. The DC module is protected with a semiconductor fuse (15A) and the input to the switch is protected with a 12A fuse. Appendix A has additional description as well as operating instructions.

Thermal cutoffs were not included as additional protection within the prototype design but are recommended. Specifically several series connected thermal cutoff devices should be installed in the heated bag in selective locations as additional protection for a patient. These devices should be current carrying devices which are normally closed below a preset cutoff temperature (75°F). If the temperature sensor or heaters become defective causing unsafe temperature levels, any one of the cutoffs will remove the power to the load when activated.

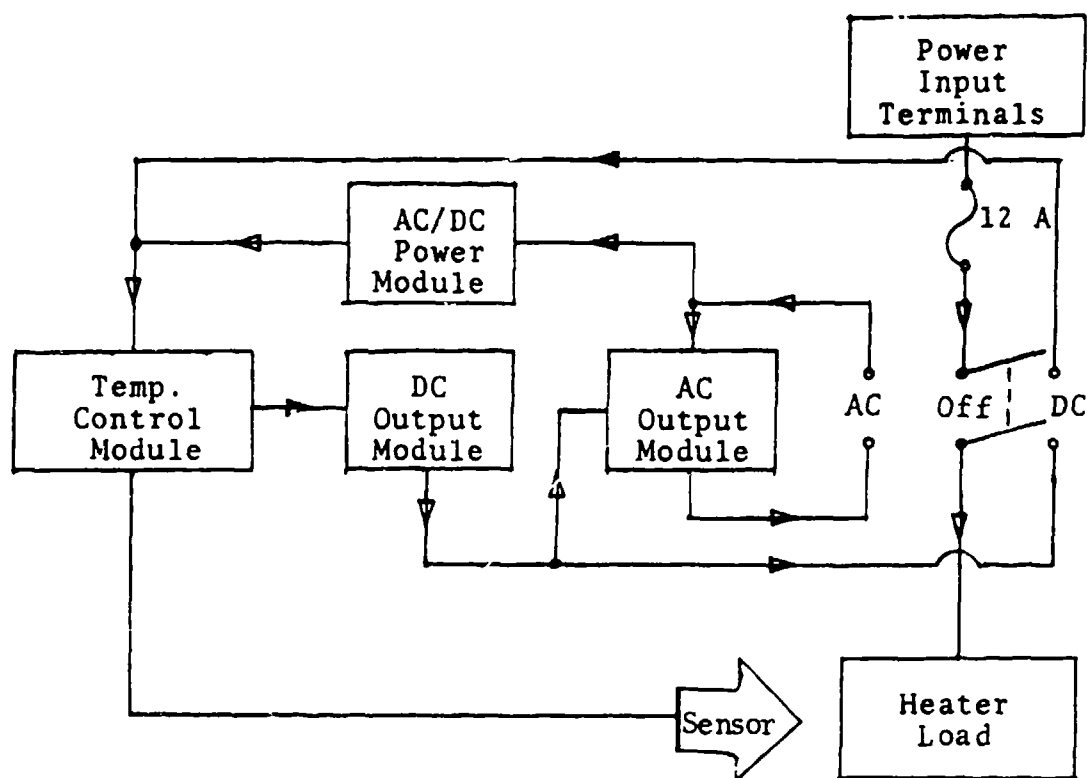


Figure 6. Block diagram of temperature controller

4.0 MATERIALS SELECTION

4.1 Inflatable Bag

Materials for the casualty evacuation prototype were selected for strength, abrasion resistance, construction and fabrication suitability, and low temperature handling and storage capability.

Two types of nylon reinforced polyurethane fabric were selected as candidates for fabrication of the prototype as designed. Both materials (A & B) are waterproof but when low temperature stiffness tests were performed, A failed by a large factor while B was found acceptable under test method 5204 of Federal Standard 191. Although both types are bondable by both dielectric heat sealing and adhesive sealing techniques, type B was found to have superior sealing qualities as measured by lap and peel tests on seals made by either method with both types of fabric.

Type B fabric was selected as acceptable for construction of the enclosure. A simple cushion structure was fabricated from the fabric and fitted with an inflation valve and a 2 psi relief valve (figure 7). It was inflated and deflated with CO₂ at room temperature 12 times successfully and showed no signs of separation around the periphery or along the rib-outer skin interface. The cushion was also inflated with CO₂ at -30°F and removed to room temperature where the increased pressure was relieved by the relief valve. The cushion handled the CO₂ inflation well and the relief valve opened at 2 pounds of pressure. The seals were fine at 2 psi with no evidence of peeling or shearing.

4.2 Harness

A roll of 1 3/4 in. nylon webbing was selected to fabricate the harness chosen as the means of carrying the prototype evacuation bag. The nylon was used instead of cotton which is preferable because it was on hand. The cotton webbing preferred would be purchased in a 2 in. width.

4.3 TES Material

The thermal energy storage materials were manufactured from the previously mentioned eutectic salts suspended in a gel. The type B nylon reinforced polyurethane fabric was selected to make panels of the TES material. Durable heavy duty snaps (corrosion resistant) were selected to attach the TES panels to the evacuation bag.

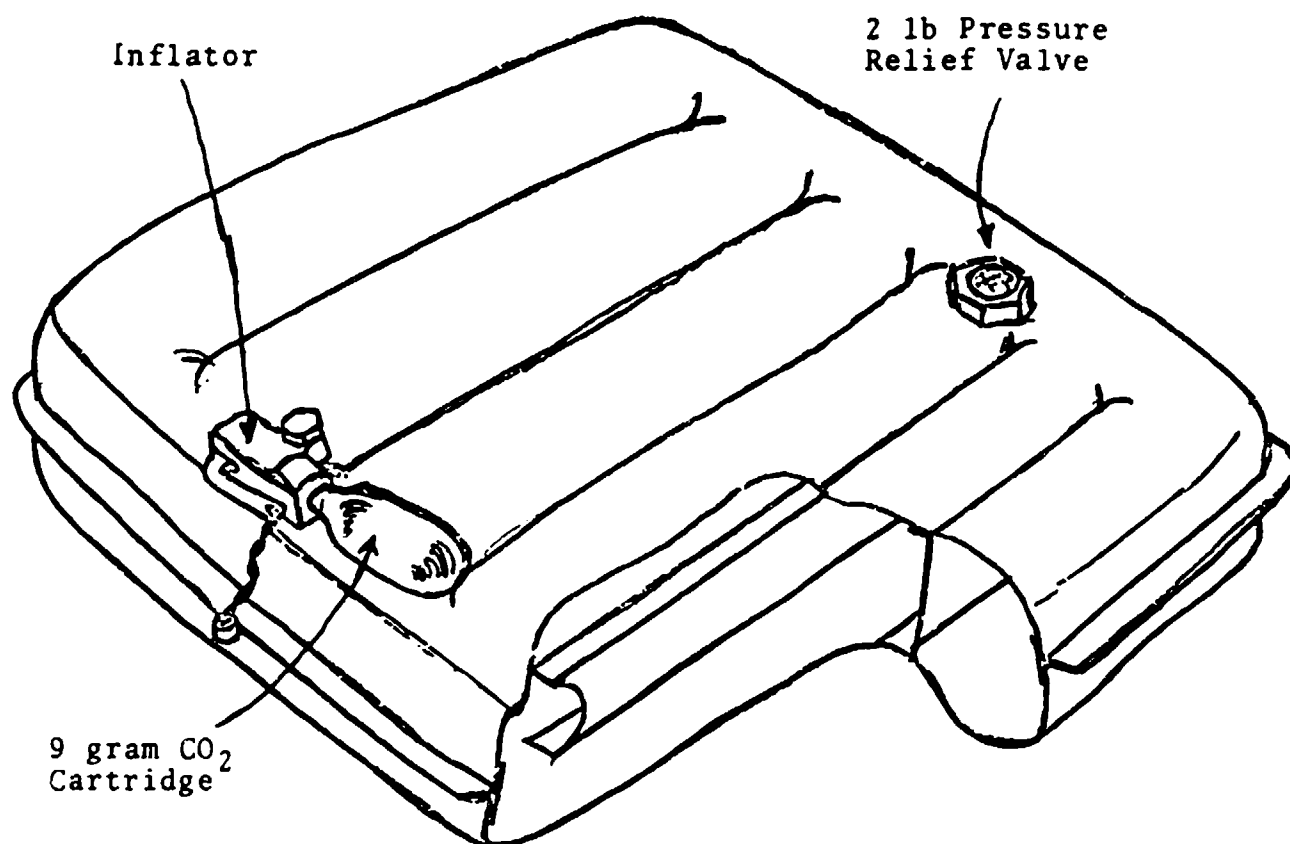


Figure 7. Test cushion

4.4 Heaters

Thirty heaters were selected for the prototype. They are flat (0.050 in.), 2 in. wide, 20 in. long and lightweight (2-7 oz/sq ft). The heaters consist of fine spiraled nickel alloy wires encapsulated in silicone rubber. They retain excellent dielectric properties when heated, resist harmful effects of severe vibration, do not crack or craze from aging, have low moisture absorption and they have good resistance to lubricating oils and a variety of chemicals. They are so flexible they can be bent 130° back on themselves with no harmful effects and demonstrate excellent handling ability at extremely low temperatures. These heaters are easily replaceable and are obtainable with pressure-sensitive adhesive or can be attached with silicone RTV adhesive to clean surfaces. The heaters are each rated for 200 watts maximum but at 28 V dc dissipate less than 10 watts each.

4.5 Liner

Nomex fabric was selected as a suitable liner material. Not only is this fabric launderable but it is extremely durable, quite fire retardant and lightweight. If an electrical malfunction were to occur the material would not burst into flame. The fabric can be sewn by conventional means and snaps easily applied for attachment to the evacuation bag.

4.6 Power and Temperature Controller

Most materials and components selected for fabricating the temperature controller are rated for low temperature operation. The temperature controller module, however was a special order and for this prototype was fabricated from non-military specification components and therefore may not control accurately at the lower temperatures. The switch and output devices are rated for low arctic temperatures and the miniature power supply should function at low temperatures. The cables interconnecting the controller unit to the evacuation bag are silicone rubber insulated and have excellent low temperature handling characteristics.

5.0 PROTOTYPE CONSTRUCTION

5.1 Inflatable Bag

The evacuation bag was fabricated in two sections, (top and bottom) each with its own inflator and pressure relief valve. The nylon reinforced polyurethane fabric was cut from a roll 46 in. wide x 0.011 in. thick. The construction procedure consisted of sealing prefabricated separator ribs (two inches on center) to two opposing outer skins by dielectric heat sealing. An inflation valve and a pressure relief valve were sealed in a predetermined area at the head end near the perimeter of each section. The outer skins were sealed together around the periphery using 1-1/4 in. bias tape of the same fabric and the top section, which was flat during previous sealing, was folded and sealed into its canopy shape. These seals were made by solvent bonding using Tetra Hydrafuran. At this point the hooded attachment was sewn together from a quilted nylon fabric such as that commonly found in ski jackets, a simulated fur piece which was added to protect the patient's face and a water resistant nylon fabric to line the inner side of the quilted fabric. The hooded attachment was sewn to the bias tape which was then solvent-sealed to the top section and the hinged side of the bottom section. The two sections were hinged together by solvent-sealing the bias tape along their two edges. The two zippers, which meet in the middle on the periphery of the unhinged side, were attached by sewing each zipper half to the 1-1/4 in. bias tape and solvent-sealing the bias tape around the periphery. With the zippers opened up, the top section can be easily lifted up and laid over on its hinged side to allow easy placement of a patient within the evacuation bag. When this stage of assembly was completed, all leaks which were detected were repaired and rechecked until the assembly held air. This completed assembly is shown in Figure 8.

The "space blanket" material was then marked and cut to proper size in three sections (See Figure 9). The top section was two separate sections which were carefully fitted to allow for expansion or reduction in surface area due to the bag's inflatable nature and still fit properly for minimum heat loss. Holes and slots had to be cut in the "space blanket" to allow for snaps and straps to protrude through for attachment of the TES modules and the heaters. The bottom section of "space blanket" was merely a rectangle which was cut to the proper dimensions and holes cut for snapping it in place in the four corners.



Figure 8. External view of the completed prototype sans temperature controller. The man inside is 6 ft-1 in. tall and weighs 180 lbs.

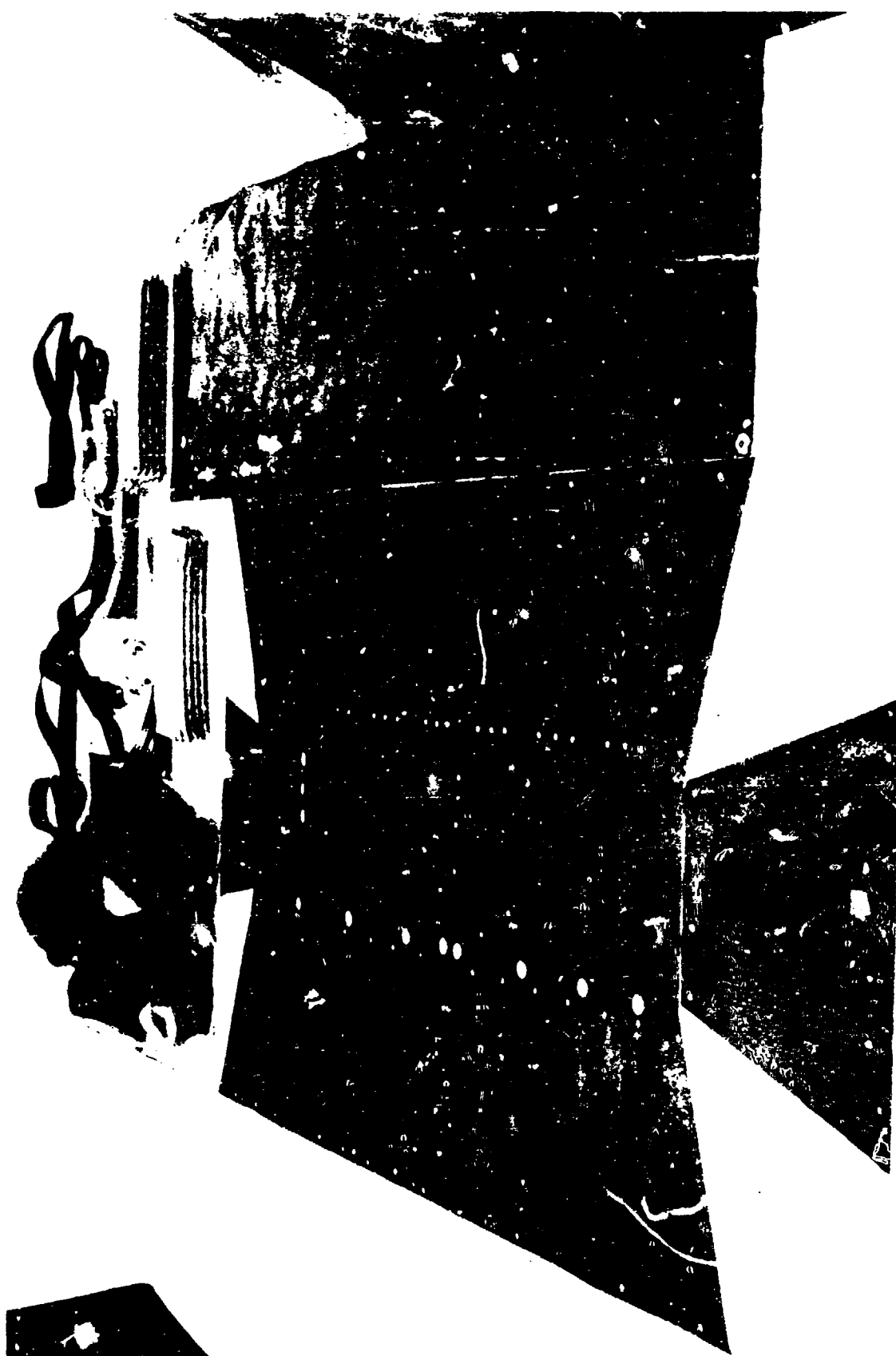


Figure 9. The non-reflective side of the "space blanket" ready for assembly. Note other assembly components in the background.

The heaters were laid in the evacuation bag in their proper places and two buss lines fabricated from approximately 20 foot lengths of silicone rubber insulated 0.192 in. O.D. stranded wire (#14 AWG, 19/27). Conventional 1/4 in. quick-disconnect slide solderless female connectors were attached to the buss lines at the proper distances for interconnection with the thirty heaters. Each of the joints where the connectors were attached to the buss was insulated with silicone RTV sealer. One buss line was insulated with black RTV and the other with white. The buss lines were attached to the bag by solvent-sealing them under loops of nylon reinforced polyurethane bias tape. Two long extensions were brought out through feedthrough grommets in the hooded section of the bag. A male two-pin connector was attached to the buss line extensions for interconnection with the temperature controller.

5.2 TES Material Packaging and Installation

Space limitations and patient comfort aided the decision to place all 16 lb of the TES material in the top section of the evacuation bag. Due to the design of the evacuation bag with its near vertically upright side and rear wall panels, the TES material was packaged in 18 modules to be mounted upright on the side and rear walls. Each of these modules was fabricated by dielectric heat sealing two layers of the nylon reinforced polyurethane fabric of dimensions as given in figure 10. The sealing was done with a specially-fabricated sealing tool which formed the four tubes in the module which were filled with the TES material. After filling, the top section was sealed off and the modules wiped clean and snaps installed as shown in the figure.

Eight modules were attached to each of the side walls and two to the rear wall. The eight on the sides were arranged with the four on the right side having a downward slope from left to right and the four on the left with a downward slope from right to left. The two snaps on the same end of the module were parallel to the bottom of the bag. The left module on the rear wall has a downward slope from right to left and the right module from left to right. The snaps made the TES modules easily replaced, removed and interchanged. The snaps are special combination types which allow a second female snap to mate to the module after it is snapped in place.

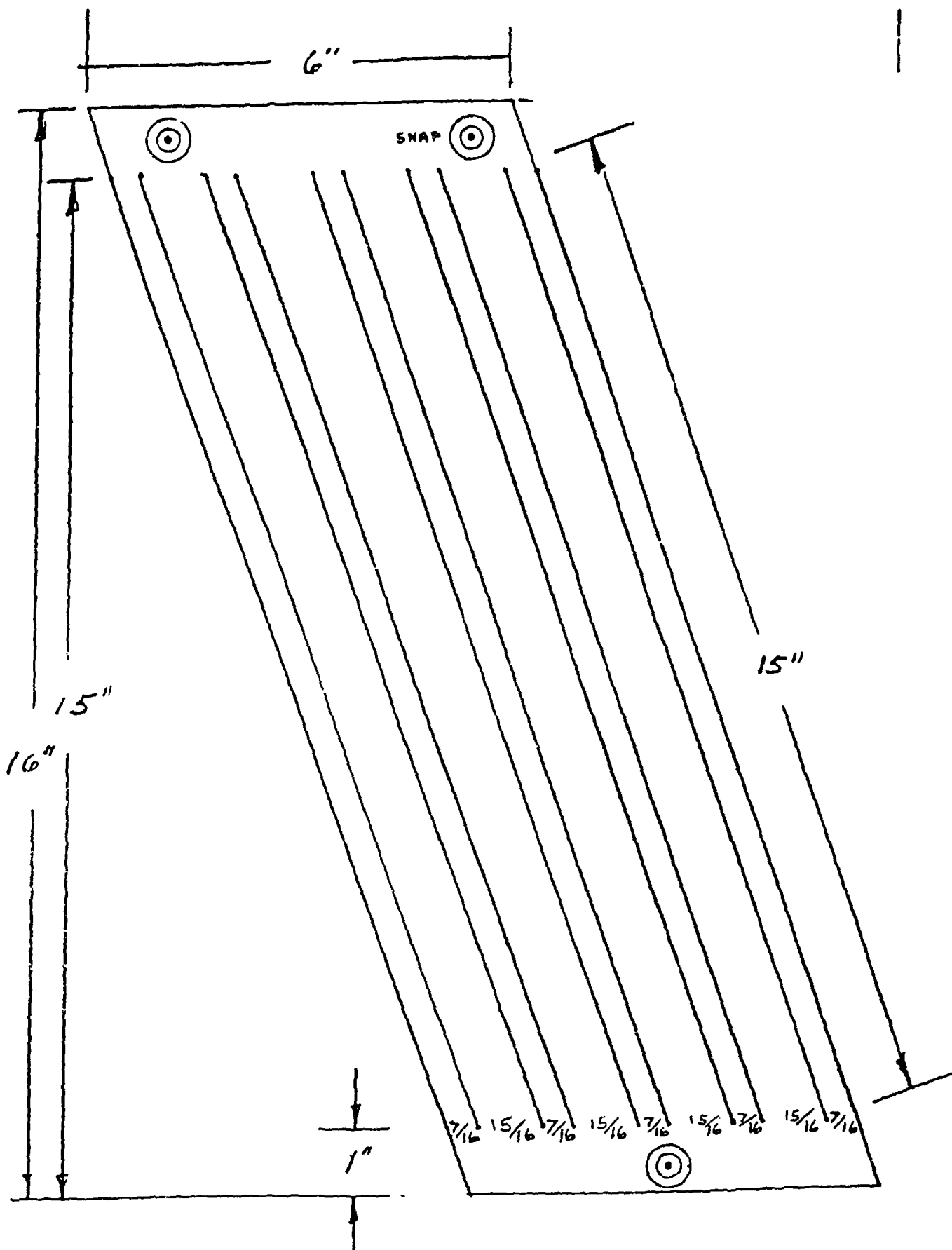


Figure 10. The sealing pattern for the TES modules and snap placement.

5.3 Heaters

The 30 heaters were positioned with 22 on the top section and 8 on the bottom (See Figure 11). The heaters in the top section were mounted by snapping them to the enclosure on one end of the heater and strapping them down on the other end with bias tape. Male snaps were attached to 3/4 in. lengths of the 2 in. cotton webbing which were then attached to the silicone heater strips with silicone RTV adhesive. The straps which hold the heaters in place at the end opposite the snap are fastened on each side of every heater by snapping one long strap to the TES modules. It can be seen from figure 11 that if a strap is fastened to these modules that it has to pass over the heaters which lie between the modules. It can also be seen in the figure that five of the heaters in the top section do not lie between any TES module. Each of these five heaters also has a snap at one end as before but the strap used at the opposite end in each case, is permanently solvent-bonded to the bag. The heaters are slipped under the strap before the electrical connection is made.

All thirty of the heaters are electrically connected by conventional 1/4 in. male quick-disconnect slide solderless connectors which mate with those female connectors on the buss line. The connectors are insulated with heat shrinkable teflon tubing to prevent any electrical contact with a patient. The heaters can be used with or without the TES modules.

The 8 heaters on the bottom have no snaps. They are held in place by sliding them into pockets formed by heat sealing strips of a thin laminate of aluminum, mylar and polyethylene, 2 1/2 in. x 4 in., onto the bottom section of the space blanket. They are connected to the buss lines in the same fashion as the others.

5.4 Liner

The liner is sewn from a roll of Nomex fabric and fitted in each corner with snaps which mount on the four corners and protrude through the space blanket bottom section. The liner covers the heaters and the space blanket on the bottom and aids in keeping the surface temperature at the patient's skin at a safe temperature (less than or equal to 90°F).

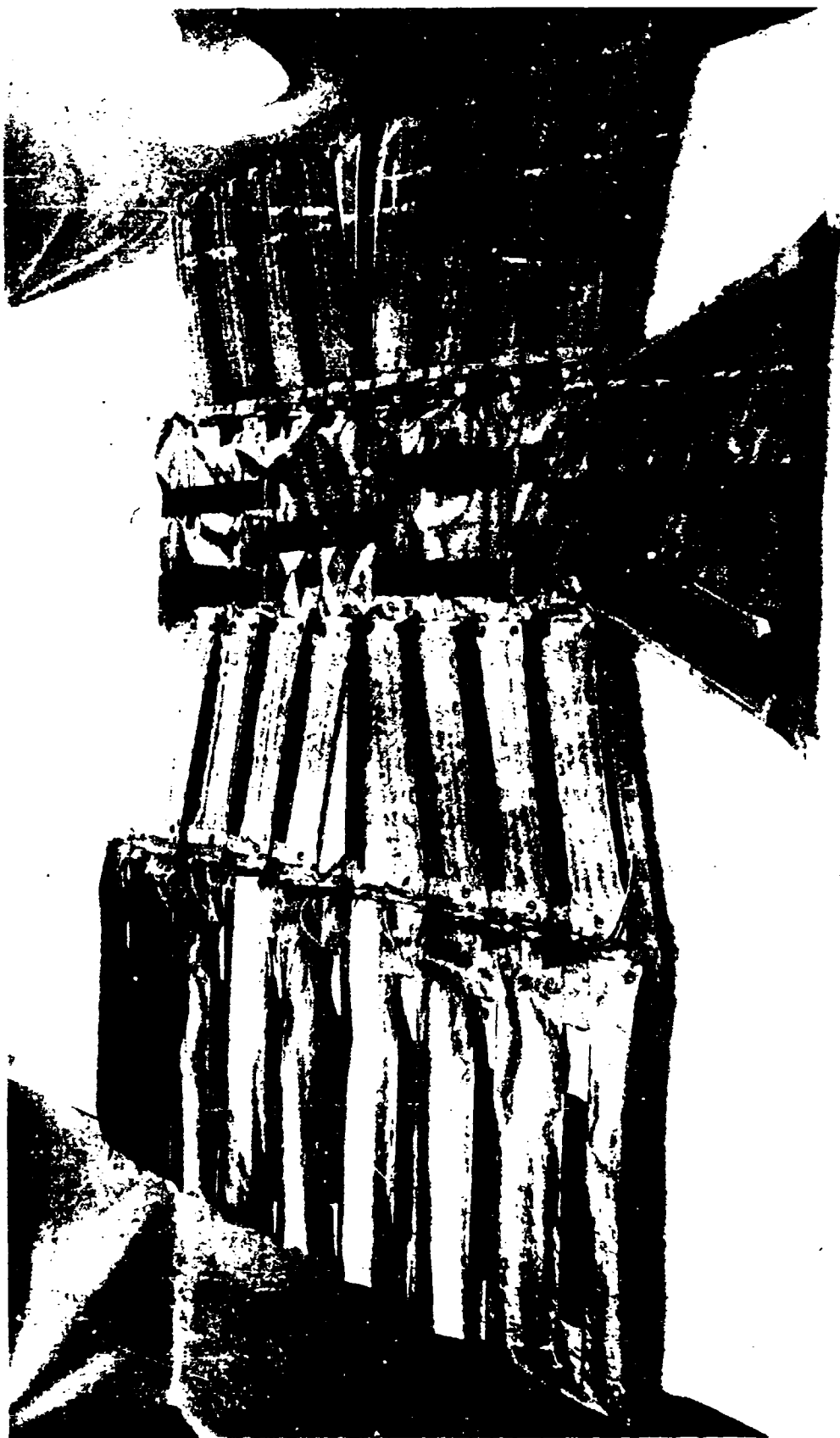


Figure 11. Layout of evacuation bag illustrating TES modules, space blanket and heater placement.

5.5 Carrying Harness

The prototype carrying harness was stitched and fabricated from references to Military Specification MIL-E-11450 using the 1 3/4 in. nylon webbing and black nylon thread. It required 12 yards of webbing to complete the harness.

5.6 Power and Temperature Controller

The prototype temperature controller was assembled with its components and modules as previously listed in Section IV mounted in a 3 in. x 5 in. x 7 in. aluminum enclosure. The dc output module was mounted externally with its wires passing through a feedthrough to the interior. The anodized aluminum heat sink on which the dc module was mounted was isolated from the aluminum chassis by bakelite spacers and nylon screws. The other external components are the power input terminals (red and black 5-way binding posts), the on-off and input selector switch, a 12 A fuse holder, a calibrated temperature dial, a female panel-mounted 2-pin connector for the heater load and a female two-pin connector for the temperature sensor. The temperature control module is mounted internally and all of its interconnections are made with 1/4 in. quick-disconnect female slide type solderless terminals. The ac output module and power supply are internally connected. The fuse holder and 15 A semiconductor fuse which protects the dc output module are mounted on the inside wall of the enclosure also.

The temperature control module operates with 12 V dc to 28 V dc input and provides an output of 12 V dc to 28 V dc as well. With a 12 V dc input, the module will have a 12 V dc output when it is on and 0 V dc output when off. The DC output module conducts high current (12 A) when biased with 28 V dc and extremely low current (in the milliampere range) when biased with 12 V dc because its only load when biased with the latter is the ac output module. Because the 12 V dc power supply is always electrically connected to the temperature control module's input terminals, it is diode protected to prevent damage to the output filter capacitor when 28 V dc is used as the input. Also a 12 V dc zener diode is used with the solid state relay control input since the relay is permanently connected across the dc output module's output leads. This prevents the light source in the photo coupler from being damaged. These protective devices were employed to minimize the number of necessary switches on the controller and effectively simplified the design to a single switch operation.

6.0 TESTING AND DISCUSSION

The completed prototype casualty evacuation bag was delivered to Fort Detrick, Maryland for a demonstration of the unit to a group of persons involved with patient evacuation and field hospitals. The prototype was delivered in a completely deflated state and tightly rolled into an approximately 2 cu ft volume. It was unrolled in the group's presence and fully inflated with a portable pump. The group asked questions related to actual evacuation problems as to how the ARTECH prototype might be adapted or suited to field situations. It was pointed out that the inflatable structure may allow suspension of an IV or blood plasma bag within the heated evacuation bag to further aid the survival of the patient.

The group placed one of their members of the 95th percentile male category within the bag and lifted him with the carrying harness. The harness seemed to support the occupied prototype well. Heaters and TES modules were removed and passed among the group for inspection. The snapping arrangement of the heaters and TES modules was demonstrated and the conclusion was drawn that extra snaps would permit many accessories to be adapted to the prototype if the accessories were equipped with snap fasteners also.

It was concluded that the prototype should have been designed to allow more shoulder room to accommodate an articulated patient of the 95th percentile male category. It was shown that by fastening the top canopy section on the bottom of the periphery of the bottom section, an additional two inches of width would be realized on each side. It was also suggested that the evacuation prototype be lengthened more to handle a field-expedient splint.

During this discussion the points were made that the prototype was of a width, height and length to allow the occupied prototype to be placed on the racks of an evacuation helicopter or ambulance. This is a critical factor because of the limited vertical space due to a stacked design to optimize the evacuation capacity. The point was also made that the prototype temperature controller was designed for 28 V dc and 24 Vdc as required but there is currently a changeover in progress from 24 V dc to 12 V dc in mobile evacuation units. This of course would increase the current flow in the heater circuits with the same power input to approximately 20 amperes, quite a heavy load.

After the meeting with this group, it was requested by the representative of the U.S. Army Medical R & D Command that the prototype evacuation bag be left at Fort Detrick for further discussion among the group. A few days later the bag was placed in the cold testing chamber at Fort Detrick and some comparison testing was attempted between the prototype and an existing standard evacuation bag. Each bag was placed on a separate table

within the chamber. The existing bag was placed on a low table and the prototype on a table several inches taller. Strong circulating air currents (due to two large fans within the chamber) beneath each bag caused an unequal increase in heat loss for the bags. Such a test should have been performed with each bag placed flat on the floor of the chamber to duplicate the expected case in which an occupied evacuation bag is left resting on the snow covered ground of the arctic. Three temperature sensors were placed within the prototype and one within the existing standard. The three within the prototype included one at the rear, six inches from the end in the center of the bottom section, one mounted to a TES module near the front and one suspended in the top section in air near the center of the unit. The cold chamber was then cooled down to -35°F and the temperatures monitored in each bag and recorded. A second test consisted of cooling the prototype down for 6 hours and then applying power to the heaters.

The results of these two testing attempts were discussed at the formal design review of the prototype at the contractor's facility. The data demonstrated that the TES material was not freezing at the designed temperature but at a lower temperature. This was attributed to the fact that the TES material requires approximately 5 cycles of freezing and melting before it performs properly. The material had not been cycled previously because testing such as that performed was neither scheduled nor anticipated at the time. It was agreed between the contractor and the government's representatives that cycling of the TES modules would be performed and further testing similar to that previously performed would be attempted again, making all efforts to duplicate actual field conditions.

The modules were cycled four more times in addition to the cycling experienced during the first testing attempts. After completion of the cycling, further testing began. It was noted that the nature of the prototype allowed circulating air currents within the bag with no patient present, this causing increased heat loss. The existing standard on the other hand lay flat on itself with negligible air space and negligible air currents. Practicality prevented placing a human with the bags for testing so a compromise was made with the placement of eight one-gallon water bottles in a similar arrangement in each bag. The water represented approximately a one hundred pound mass and would evolve its sensible heat to the enclosures as the temperature dropped. This was a crude attempt to compensate for the heat involved by a wounded man as well as his bulk.

The first test of this round began by placing the bags side by side on a 1/2 in. plywood floor. The testing was performed with the TES modules removed from the prototype. Two temperature

sensors were placed in each bag being tested, one in a water bottle and the other in the center of each bag suspended in air. The temperature in the cold chamber was lowered to -40°F in approximately one hour. It was noted that the prototype became visibly deflated at the lower temperature due to a proportional drop in its pressure. This of course could affect the insulation properties of the unit in a negative manner. In both bags, the air temperature dropped at a much faster rate than the water temperature. The air temperature in the prototype dropped much faster than the air temperature in the existing standard and the water temperature in the prototype dropped faster than the water temperature in the standard.

After two hours in the cold chamber the water temperatures in the two bags differed by roughly 5°F the lower temperature being at 68°F . However, the temperature differed by 21°F between the two air temperatures, with the lower being roughly 32°F . This large difference appeared to be potentially a direct result of the aforementioned deflation experienced in the prototype due to pressure drop. It was also noted that an additional sensor to monitor the temperature of a water container not enclosed in one of the two bags but within the cold chamber would be desirable.

With these considerations, a second test was performed with the cycled TES modules installed in the prototype. Extension hoses were fastened to the two inflation devices of the prototype and brought outside the chamber through a feed-through to allow oral topping off of the pressure in the prototype. The bags were left on the floor of the chamber as before and one water bottle was removed from each evacuation bag. They were both placed on the plywood-covered chamber floor and a temperature sensor placed within the water in one of them. The other four sensors were positioned as before with two in each bag.

Again the temperature dropped to -40°F in roughly one hour. The prototype was orally topped off with air at about 0°F and again at -40°F at which point no sagging was noted. The prototype lost heat at a faster rate again but not as fast as previously. After one hour the water temperatures in each bag had remained the same but the heat loss rate of the water in the prototype began to increase slightly. The air temperatures differed by $4\frac{1}{2}^{\circ}\text{F}$ after one hour and by only 4°F after two hours. This is attributed to the presence of the TES material in the prototype and is a direct result of its 55°F freezing point. After three hours the air temperature difference was $6\frac{1}{2}^{\circ}\text{F}$ with the air temperature in the prototype at 48°F . The uninsulated water bottle lost heat to the chamber quite rapidly. After $1\frac{1}{2}$ hours, the temperature difference between the uninsulated water bottle and the water

bottle in the prototype was 35°F with the lower having dropped to 44°F.

The TES material began freezing at 55°F as expected during this test which verifies the necessity for temperature cycling prior to insertion into the system. However, the material appeared to have frozen in approximately 53 minutes once it had evolved all of its sensible heat instead of the 120 minutes it had been designed for. This indicates the need to increase the surface area in the TES modules by at least 126%.

The validity of any of these data is questionable. In fact, in the same day under the same conditions with the same temperature sensors the heat loss rate of the existing standard evacuation bag was much greater in the first test than it appeared to be in the second. It was so inconsistent that in the first test of the day, if it were compared to the heat loss rate of the prototype in the second test that of the prototype would be found superior to the standard. Likewise the heat loss rate of the water in the standard bag in the first test was inferior to the heat loss rate of the water in the second test. These data may be helpful for crude evaluation of the prototype but a much more comprehensive testing program must be devised before meaningful data can be gathered. Further testing should include many more sensors and recording instruments as well as a method of inserting a physiological model of a human in shock in each bag. While lowering the chamber temperature to -40°F, the bags should be electrically heated to maintain the internal temperature at 70°F. Then power can be removed and a better indication of the performance of the TES material can be obtained.

The prototype evacuation bag was not returned to the contractor for the duration of the contract performance period. No further testing was possible with the temperature controller unit and the load for which it was designed. No cold chamber testing was performed on the temperature controller unit by the contractor or the government prior to the expiration of the contract performance period. All deliverable contract line items were delivered at the expiration of the contract.

7.0 CONCLUSIONS

The electrically heated, inflatable casualty evacuation bag prototype designed and fabricated by ARTECH CORP. for the U. S. Army Medical R & D Command functioned as designed and demonstrated the feasibility of the approach.

The prototype was shown to comfortably enclose a 95th percentile male but it is recommended that the width be increased 2-4 in. to accommodate bulky clothing and the length be increased roughly 4 in. to accommodate a Thomas splint. Heavier zippers should be substituted for those used in the prototype and extend further around the periphery of the bag into the hinged side to relieve all tension on them. The hood should be made larger to cover more of the patient's face as necessary.

With the limited data available, the prototype design offers no advantage over the existing standard in insulation properties. Much more comprehensive testing must be performed however, before an accurate comparison can be drawn between the prototype and the existing standard. The limited testing performed indicated excellent insulation properties for the existing standard evacuation bag, but only moderate insulation properties for the prototype.

While the prototype appeared not to outperform the existing standard, certain features are worthy of note.

The thermal energy storage system is innovative and indicates great potential for maintaining a patient after loss of power. The insertion of thermally charged modules into an evacuation bag can greatly aid in maintaining a casualty. The testing performed indicated the need for additional surface area in the packaging of the TES material to allow the material's stored thermal energy to be released to the enclosure within the necessary time frame. The testing would indicate that the 16 lb of TES material installed may be superfluous if the surface area is increased. This, of course, would indicate a reduction in weight and therefore aid in the portability of the prototype.

The electrical heaters provided in the prototype, although untested, should prove to be quite adaptable to the existing standard evacuation bag as well as the prototype. The temperature controller in conjunction with these heaters or any similar resistive heater array also has desirable qualities which can be utilized by the existing standard bag. Further testing is recommended to place on record the performance characteristics of the heaters and temperature controller.

The inflatable prototype provided still another potential advantage in that there is no bulky mass resting on the patient as there is with the existing standard. This could prove extremely uncomfortable and painful for a patient with a large chest injury or even a foot injury. An extremely lightweight inflatable rib structure could be added to the existing standard bag if it is felt to be a serious factor in patient survival. However, if the insulation properties of the existing standard evacuation bag are significantly improved with no weight increase, the improved design should easily maintain a patient at a comfortable temperature for over two hours with no power. On moderately cold days, however, the improved version could conceivably keep a patient uncomfortably warm where TES material would release its heat at a rate proportional to the ambient temperature. Therefore, if the potential advantages of the prototype's structure are found to be negligible, an existing standard bag could successfully be modified with an electrically heated liner and temperature controller such as that contained in the prototype's heating system. It could also be modified by adding the suggested inflatable rib structure and some thermal energy storage material for special needs.

APPENDIX A.

**OPERATING INSTRUCTIONS FOR THE ARTECH CORP.
PROTOTYPE INFLATABLE AC/DC HEATED CASUALTY EVACUATION UNIT**

**Prepared for
U.S. Army Medical Research
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Washington, D.C. 20314**

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OPERATING INSTRUCTIONS FOR THE ARTECH CORP.
PROTOTYPE INFLATABLE AC/DC HEATED
CASUALTY EVACUATION UNIT

1. Description of Evacuation Unit

The bag structure of the unit has two sections, a bottom and a hinged top or canopy arrangement each with its own inflation point. The unit will be stored while deflated and rolled into a compact bundle less than two cubic feet in volume. The unit is heated by 30 silicone rubber strip heaters which are attached to the inner surfaces of the bag. The heaters are powered by either 24 VDC, 28 VDC or 110 VAC. The thirty heaters are paralleled with one male two-pin connector extending from the bag to a female two-pin connector on the temperature controller. The temperature sensor fixed within the bag is connected to the controller by a two-pin connector. The power is connected to the temperature controller via two binding posts, a red one and a black one. The red post is positive (+) and the black post is negative (-) for DC operation and there is no polarity consideration necessary for AC operation. The controller is operated by one 4PDT switch which has a center off position and AC "ON" and DC "ON" positions. The controller is protected by 2 fuses. The temperature set-point is set with a calibrated dial between 53°F and 86°F.

2. Inflation Procedure

The bag should be unrolled and placed with its bottom side down. Both sections should be inflated to the point where air escapes from the pressure relief valves (approximately 1 1/4 psi). The top section can be raised after unzipping the zipper to allow a casualty to be placed within. The hooded section should be zipped after the patients head is comfortably positioned within the sides rezipped. If a drop in temperature is experienced the two inflatable sections can be topped off orally if necessary. If the evacuation unit is transported in an inflated state from a warm environment to a cold environment, the temperature difference will cause a pressure drop within the bag to the point where sagging will be evident and both sections should be orally topped off with air.

3. Temperature Control

The controller should be set for a 70°F temperature setting. This is a proportional type controller with two separate output switching devices for AC and DC operation.

CAUTION! BE SURE THE POWER SWITCH IS IN THE AC POSITION FOR AN AC INPUT AND THE DC POSITION FOR A DC INPUT.

The heater connector must be connected to the controller and the temperature sensor must be connected in place for control to be possible. The load currents switched by the controller output devices are each approximately 10 amperes. The DC output device is a 16 ampere Darlington power transistor. The AC output device is a hybrid 15 ampere solid state relay which serves the dual function of switching and phase-controlling the 115 VAC input to a level suitable to produce the desired current flow. The relay output is field adjustable with a trimmer pot accessible on the bottom of the controller module with the casing removed. The relay is controlled with a 12-28 VDC input. The positive DC input lead must be connected to the red (+) binding post and the negative DC input lead to the black (-) post.

4. Basic Theory of Operation

The operation is centered around a ten-pin module which is DC powered and provides a proportional output determined by the thermistor sensor input and the calibrated dial setting. The thermistor corresponds to the calibrated scale only when calibration procedures are performed. These are explained later. The output from this control module drives the darlington transistor amplifier either on or off for full conduction of load current or no conduction of load current but at a switching rate proportional to the temperature at the sensor. For DC operation the load is switched in series with the transistor and for AC operation the load is switched in series with the solid state relay. The relay input is controlled by its series connection to the transistor. The transistor is protected by a semiconductor fuse (15 amperes) and the power input is fused with a 12 ampere fuse. The controller unit consists of 3 basic replaceable modules; the controller module, the solid state relay module and the transistor module. The 12 VDC power supply which powers the controller module for AC operations might be considered a separate module as well.

5. Calibration of the Temperature Scale

Included with the temperature controller is a 1820 Ω resistor which is connected to the sensor input for calibration. With an indicating device connected as a load or to the load, connect a suitable power source to the controller and rotate the control potentiometer until the controller turns on as indicated by the device at the load terminals. If at this point the calibration mark on the temperature scale does not correspond to the fixed reference mark on the panel, loosen the scale with an allen wrench and adjust it properly and retighten. The scale should now be calibrated.

6. Maintenance to the Bag

The heaters are replaceable by unsnapping them and disconnecting them electrically from the buss lines. The thermal storage units are removeable also by unsnapping them from their positions. This may be desirable to cut down on weight when conditions aren't so cold or for thermally charging the storage units while an evacuation bag is not in use. They can also be charged while in place within the bag by placing the entire bag in a warm environment. Leaks in the urethane bag can be repaired by a field patching kit which can be made available.

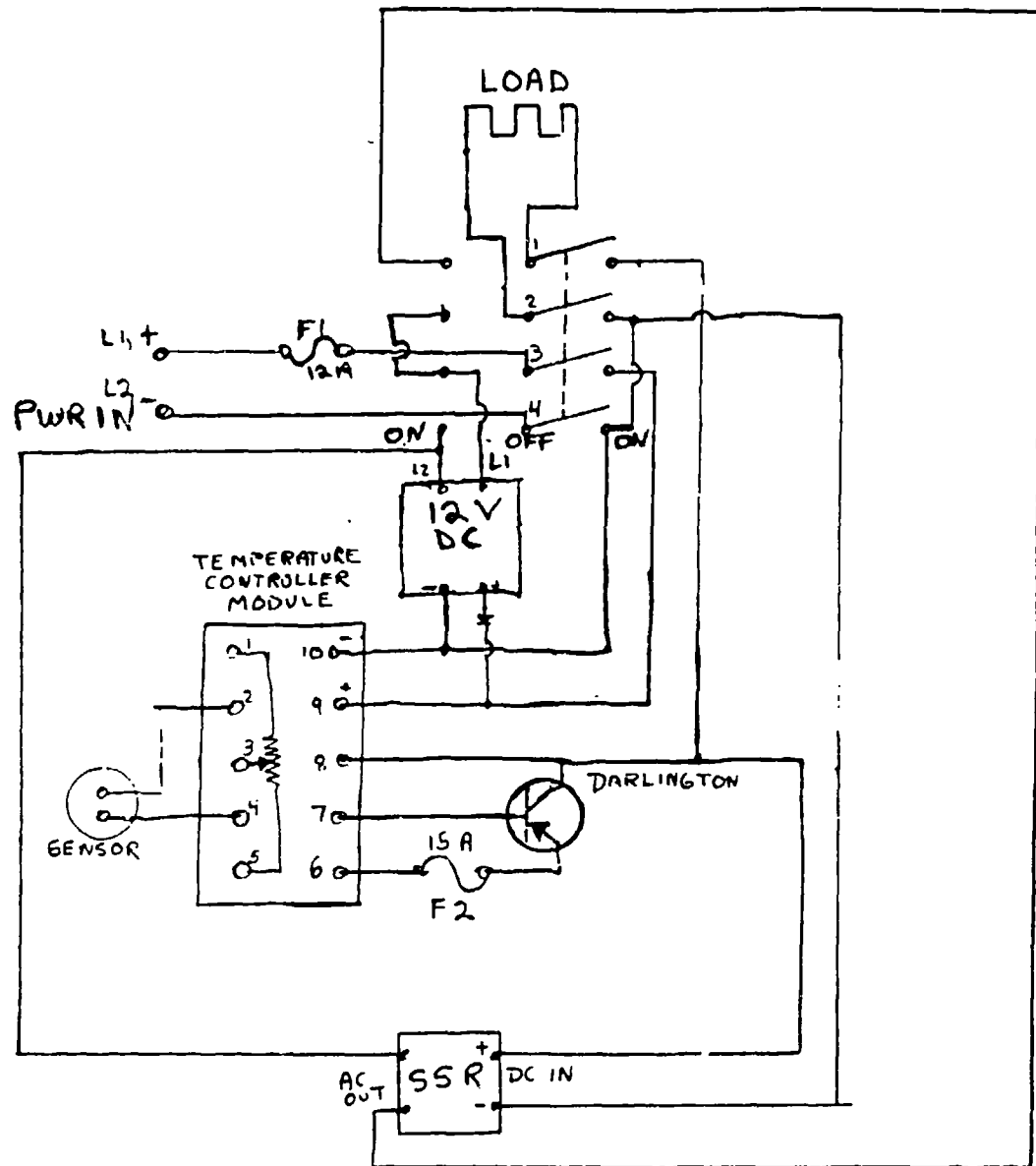


Figure 1. Schematic diagram of the Controller Circuitry